Preliminary Conceptual Analysis for an SNS Chopper Spectrometer with 1% Energy Resolution

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<u>Outline</u>

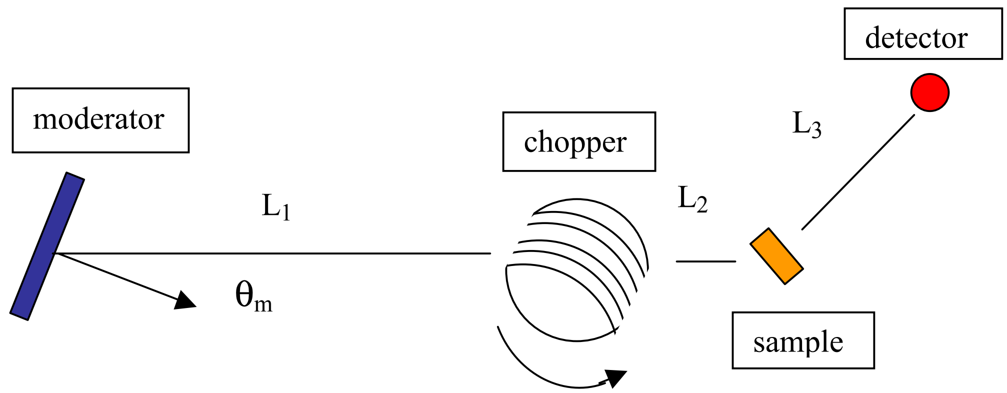
Chopper Spectrometer Basics
- Layout
- Basic Resolution
- Optimization (basic version)

Proposed SNS Chopper Spectrometer
- Layout
- Specification summary
- Costs
- Performance

Summary
- R & D efforts
- Design questions

IOC recommendation:
"The chopper spectrometer would serve the needs of several of the working groups that called for an inelastic scattering instrument with a resolution of 1% of the incident energy. This spectrometer should have position sensitive detectors covering a wide solid angle with nearly complete coverage for scattering angles < 30 degrees. It seemed to the committee that the 1% specification was too good for many applications and probably not good enough for a few others. Thus the SNS should explore a modular design so that, for example, choppers can easily be interchanged."

Chopper Spectrometer Schematic Diagram



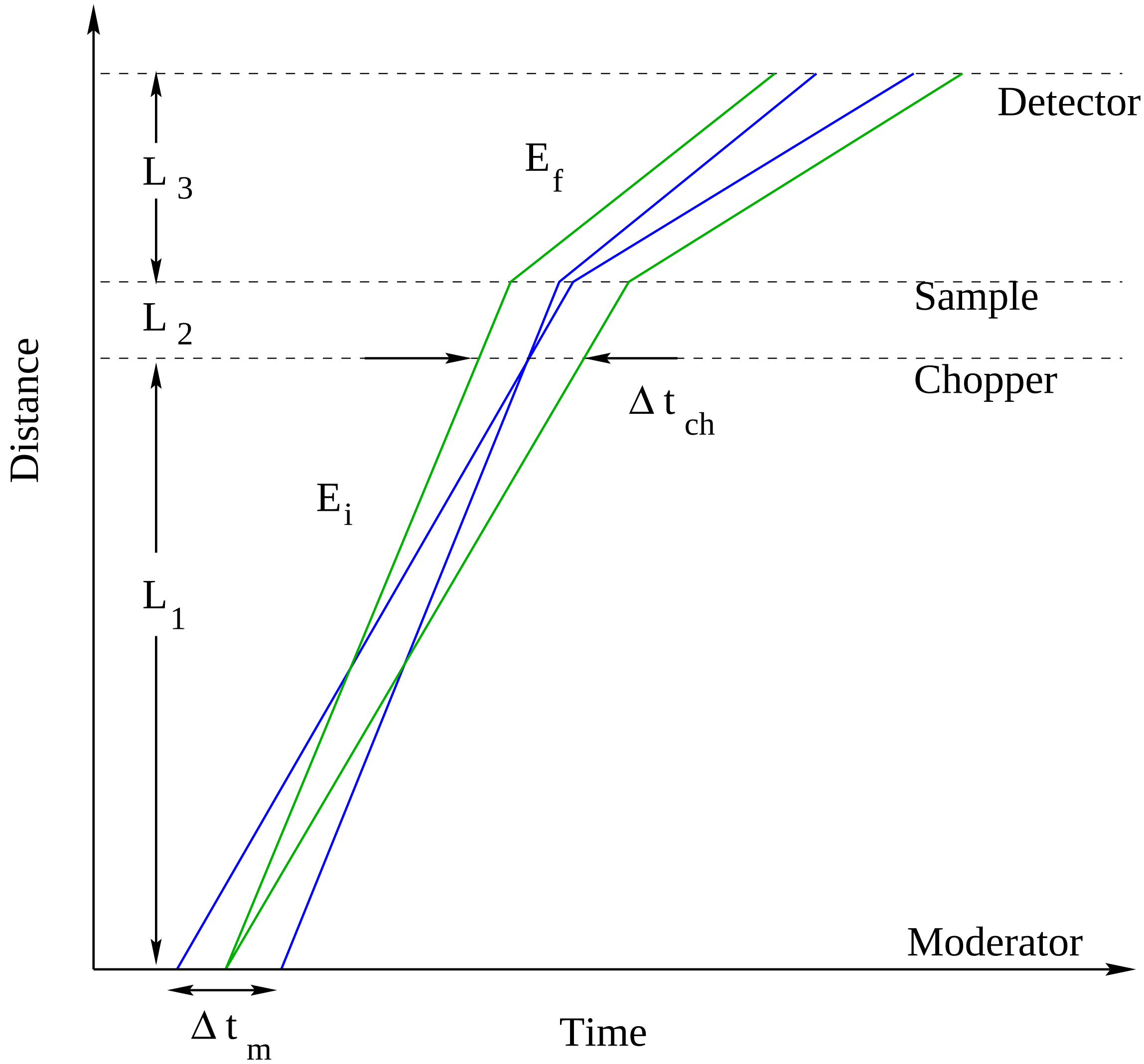
<u>Parameters</u>

L_1 Moderator-Chopper distance
L_2 Chopper-Sample distance
L_3 Sample-Detector distance

Δt_m Moderator pulse width (FWHM)
Δt_{ch} Chopper pulse width (FWHM)

t_1 Moderator-Chopper flight time

Basic Energy Resolution



$$\frac{\Delta\varepsilon}{E_i} = 2\left\{\left(1+\frac{L_2}{L_3}\left(\frac{E_f}{E_i}\right)^{\frac{3}{2}}\right)^2\left(\frac{\Delta t_m}{t_1}\right)^2 + \left(1+\frac{L_1+L_2}{L_3}\left(\frac{E_f}{E_i}\right)^{\frac{3}{2}}\right)^2\left(\frac{\Delta t_{ch}}{t_1}\right)^2\right\}^{\frac{1}{2}}$$

Energy Transfer $\varepsilon = E_i - E_f$

Basic Optimization

Observations:

- Energy resolution for a fixed moderator-sample distance always improves as L_3 increases and L_2 decreases.
  Set them by practical constraints.

- There is a maximum in flux for a given energy resolution as L_1 is varied for fixed L_2 and L_3.
  Maximize flux on sample by varying L_1.

The flux I on the sample is given by

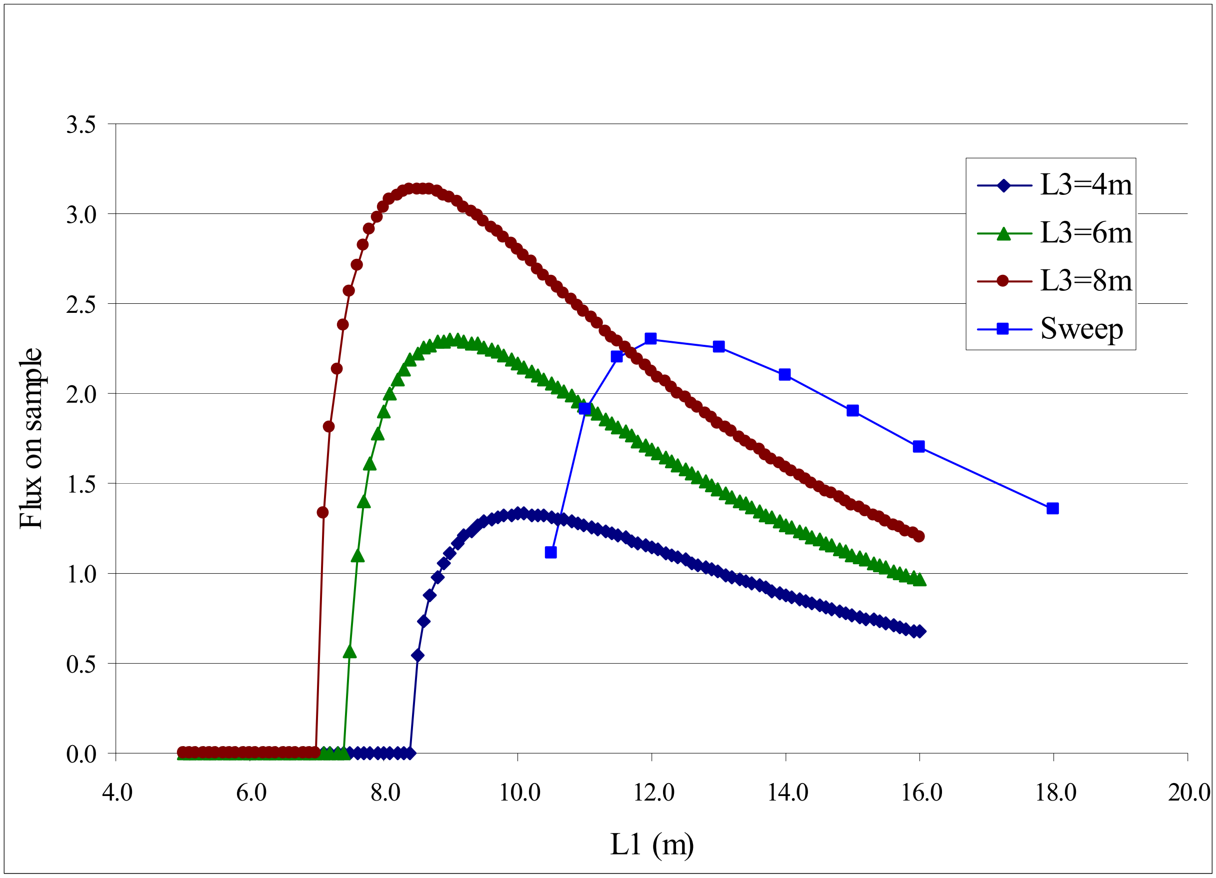
$$I \propto \frac{1}{(L_1 + L_2)^2} \left(\frac{\Delta t_{ch}}{t_1} \right)$$

Applying these to an ambient water moderator in the epithermal regime, where $\Delta t_m / t_1 = 28\text{mm}/ L_1$, for elastic scattering:

$\Delta\varepsilon/E_i$ (%)	L_1(m)	L_2(m)	L_3(m)	I (arb)
0.50	19.8	2.00	4.00	0.12
0.50	17.7	2.00	6.00	0.23
0.50	16.7	2.00	8.00	0.33
1.00	10.1	2.00	4.00	1.33
1.00	9.0	2.00	6.00	2.30
1.00	8.5	2.00	8.00	3.14
2.00	5.2	2.00	4.00	11.45
2.00	4.7	2.00	6.00	18.03
2.00	4.4	2.00	8.00	23.18

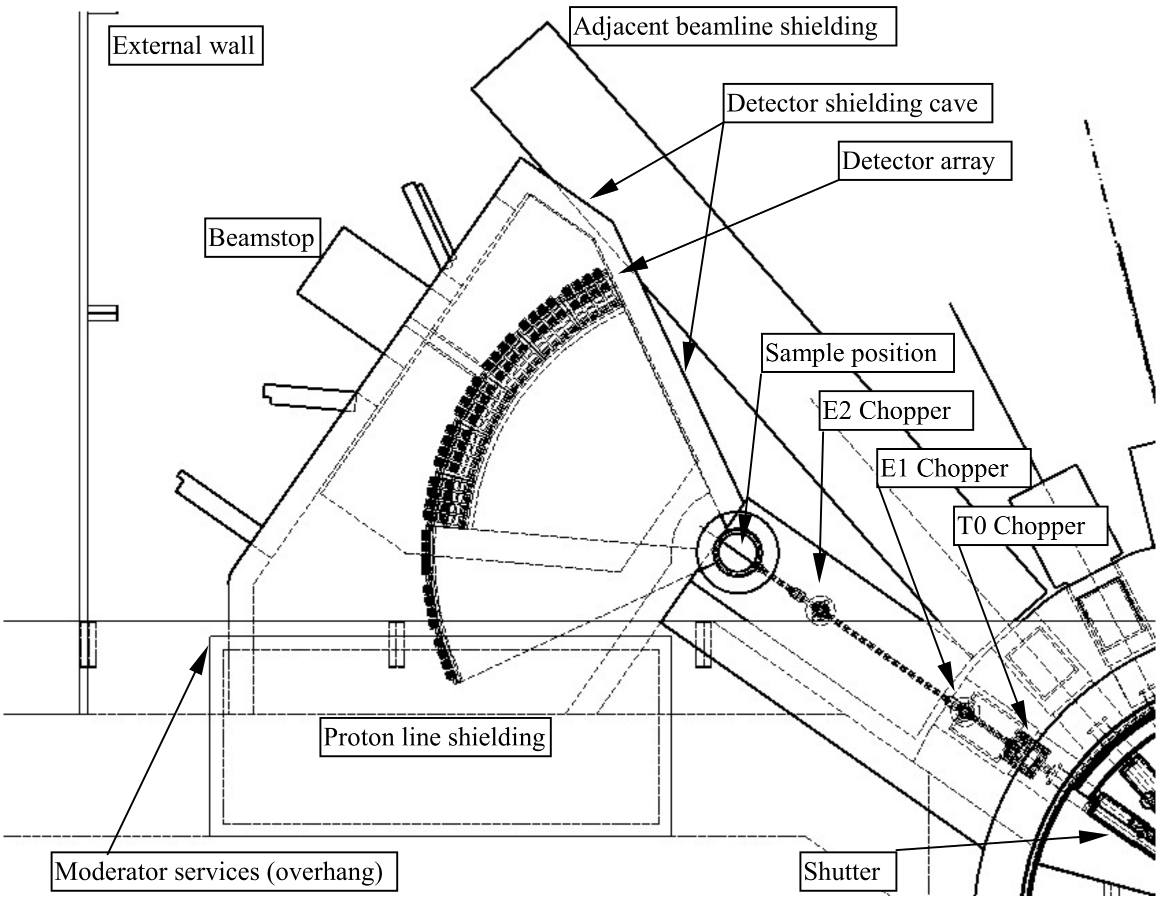
Basic Optimization (cont)

For $\Delta\varepsilon/E_i = 1\%$,

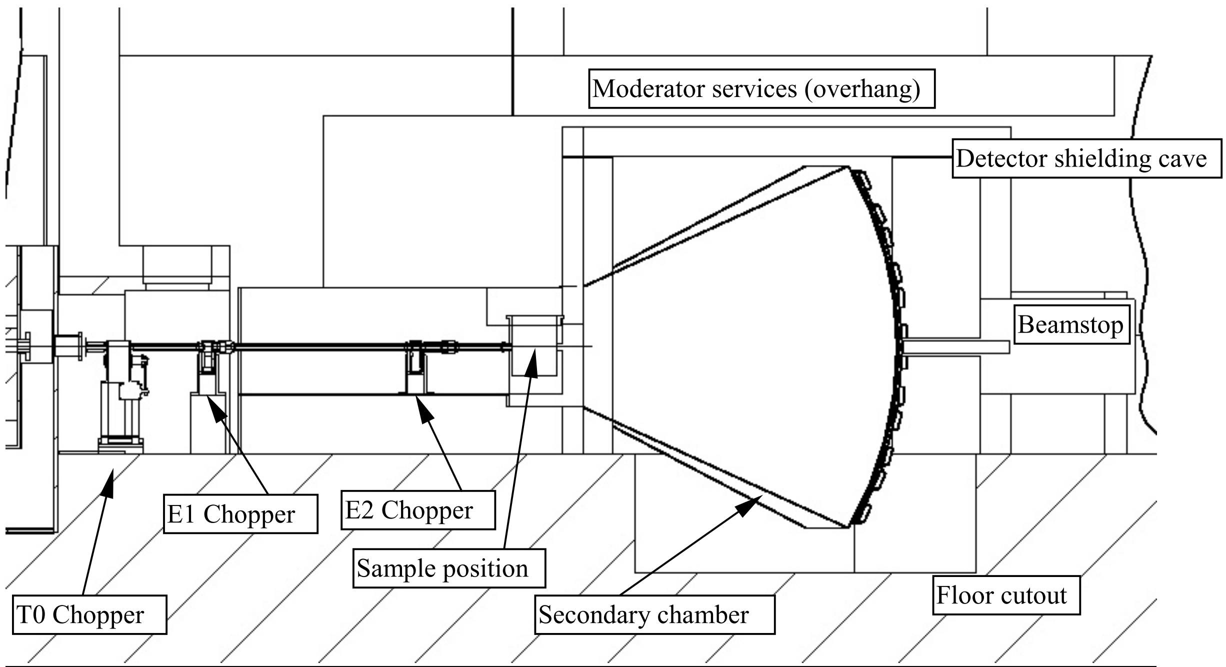


Using an analytical model which includes the sweep time of the chopper across the face of the moderator (CHOP by T. Perring, ISIS) shows that the optimum value for L_1 increases when other factors are taken into account.

Layout (top view)



Layout (side view)



Specification Summary

Moderator	Type Dimensions	Ambient H_2O decoupled poisoned 18BU 100mm(H) x 120mm(V) @ 13.75°
Geometry	Moderator-last chopper (L_1) Last chopper-sample (L_2) Sample-detector (L_3)	11m 2m 6m
Choppers	T0 horizontal axis E1 vertical axis Aperture E2 vertical axis Aperture	Mechanical 60 Hz @ 6.0m Magnetic 600 Hz @ 7.5m 85mm(H) x 115mm(V) Magnetic 600 Hz @ 11m 50mm(H) x 75mm(V)
Guide	Type Length	Tapered supermirror 3m between E1 and E2 2m upstream to be evaluated
Beamline Shielding	Steel /paraffin thickness Length	0.75m/0.25m 6.5m
Apertures and collimators	After E1 chopper After E2 chopper After E2 chopper	Variable Soller collimator Variable
Sample	Size	50mm(H) x 75mm(V)
Scattering and sample chamber	Radius sample-detector Height Vacuum at sample Vacuum flightpath Collimation Shielding, inner Shielding, outer	6m 6m $< 10^{-6}$ torr $< 10^{-2}$ torr (may be same as sample) Oscillating radial collimator B_4C, 120m^2 ~0.5 m (TBD) thick, 200m^2
Linear position sensitive detectors	Number Type Diameter Length Resolution Total pixels Angular range, horizontal Vertical, low bank Vertical, high bank Low bank solid angle/area High bank solid angle/area Total area	1400 ^{3}He 10 atm 25mm 900mm 25mm 50,400 -30° to -2°, 2°-30° (low), 30°-60°(high) ± 30° ± 10° 0.70 sr / 26 m2 0.12 sr / 4 m2 30 m^2

Estimated Costs (unburdened)

Item	Quantity	Unit	Unit Price	Total (k$)
SNS Chopper Spectrometer				9877.2
Detectors & Data Acquisition				4017.9
LPSDs 25mm x 900mm	1400	ea	1.5	2039.8
Electronics for LPSDs	1400	ea	1.0	1400.0
Mounts for LPSDs	1400	ea	0.4	560.0
Control Electronics	1	ea	10.0	10.0
Data Acq. Cabin, furnished	1	ea	8.1	8.1
Primary Flightpath				897.4
T0 Chopper	1	ea	150.0	150.0
E1 Background Chopper	1	ea	230.0	230.0
E2 Fermi Chopper	1	ea	230.0	230.0
Chopper Elevator	2	ea	20.0	40.0
Neutron Guide	5	m	15.5	124.0
Beamline Rough Vac Pump	1	ea	7.5	7.5
Beamline Collimators	5	m	5.0	25.0
Soller Collimator	1	ea	10.0	10.0
Variable Ap Collimator	2	ea	40.5	81.0
Secondary Spectrometer				1162.8
Scattering Chamber	1	ea	1000.0	1000.0
Scatt Chamb Fast Pump	1	ea	41.2	41.2
Samp Chamb Turbo Pump	1	ea	32.1	32.1
Osc. Radial Collimator	1	ea	50.0	50.0
Safety Interlocks	1	ea	20.0	20.0
Jib Crane & Air Hoist	1	ea	4.5	4.5
Instrument Services	1	ea	15.0	15.0
Sample Environment				169.1
Sample Diffractometer	1	ea	50.0	50.0
Displex	1	ea	34.1	34.1
Sample Changer	1	ea	20.0	20.0
Furnace	1	ea	65.0	65.0
Shielding				630.0
Beamline Shielding	6.5	m	20.0	130.0
Beamstop	1	ea	60.0	60.0
Inside Spectrometer	120	m^2	2.0	240.0
Outside Spectrometer	200	m^2	1.0	200.0
Effort				3000.0

Performance

- Energy and Q ranges

$\Delta\varepsilon/E_i$ FWHM	E_i (meV)	λ_i (Å)	E_f/E_i	elastic Q-range horizontal (Å^{-1})	elastic Q-range vertical [low,high](Å^{-1})
1%	10	2.86	0.4	0.08 – 2.2	[±1.1, ±0.4]
	20	2.02	0.1	0.11 – 3.1	[±1.6, ±0.5]
	1000	0.29	<0.01	0.77 – 22	[±11, ±4]

- The Q resolution is set by the energy resolution and source or detector angular ranges. The energy contribution to the resolution as a fraction of the incident neutron wavenumber k_i is 0.5% and the angular contributions from the source and detector sizes are <1%.

- The relative flux for SNS compared to ISIS ignoring any differences due to target/moderator/instrument configuration is

$$\frac{I_{SNS}}{I_{ISIS}} \approx 15.$$

Thus 12 hour data collection times should become on the order of 1 hour, allowing more sample orientations and parametric studies.

R & D Efforts

- Choppers – larger beamsize; faster; better transmission
- ^{3}He polarizers – 10 x 10 cm^2 incident beam;
  wrap-around analyzer
- Focusing optics for high energies – multichannel funnels
- Detectors – square/rectangular crosssection; packaging for in vacuum mounting and better tiling
- Software – Monte Carlo modeling; data analysis and visualization

Questions

Questions: Are these the correct compromises to make in order to build a high resolution instrument? What are other performance criteria should be taken into account, e.g. Q-resolution, higher Q limit, more flux with less resolution, etc.? What would be a prioritized list of possible chopper spectrometers? At what point is it better to use crystal monochromator based instruments?

Action: A meeting of the Instrument Advisory Team for chopper spectrometers will be called early this fall. The group will be given the charge to make a detailed, ranked listing of chopper spectrometers and their operating parameters. The scientific justification for this list and sets of parameters must be made, including examples of experiments that will be possible with a new SNS chopper spectrometer.

Questions: What are the new opportunities for different operating modes of a chopper spectrometer?

Action: Continue evaluation of neutron guides or other focussing optics, including understanding their effect on Q- and E-resolution. Using analytical and Monte Carlo techniques, see if there is an advantage to a two chopper setup for pulse shaping and flexible energy resolution.